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Construction and Bench Testing of a Prototype of 11.4GHz Externally Powered Dielectric Loaded Traveling-wave Accelerating Structure

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I. Introduction

The proposed use of RF driven dielectric based structure for particle acceleration can be traced to the early 50's [1]. Externally powered X-band traveling-wave accelerating structure based on dielectric-lined circular waveguide is proposed as a potential solution for new generation of very high-energy accelerator [2]. This kind of dielectric loaded accelerating structure has some valuable advantages:

- Simplicity of fabrication – the device is little more than a tube of dielectric surrounded by a conducting wall cylinder. This can be a great advantage for high frequency (>10GHz) structures compared to conventional structures. Also the relatively small diameter of these devices facilitates placement of quadrupoles around the structures.
- Reduced single bunch beam break-up (BBU) – the frequency of lowest deflecting mode is lower than that of the acceleration mode.
- Simple reduction of coupled bunch – it has been shown that it is relatively straightforward to build deflection damping into dielectric structure so that very large absorption of all but TM_{0n} modes can be obtained.
- Simple reduction of deflecting field – there is a relatively simple method using slotted cavity structure to attenuate the deflection modes [3, 4].

Schematic drawing of this structure is shown in figure 1.

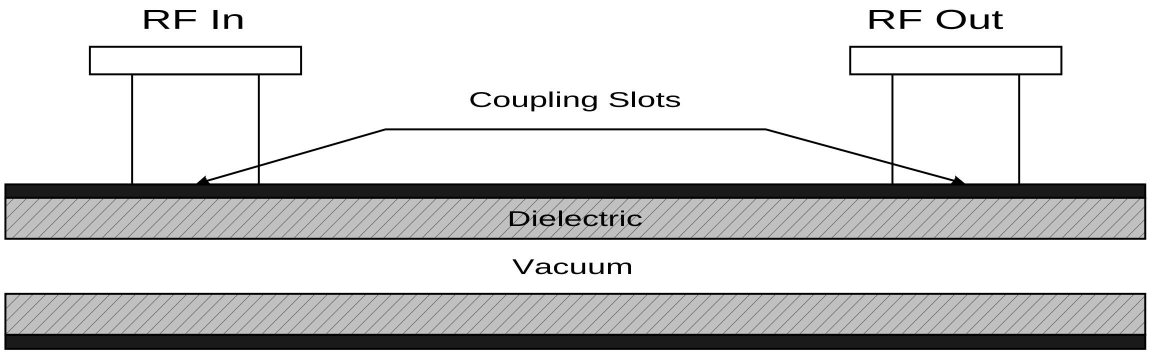

Figure 1. Scheme of an externally powered dielectric loaded traveling wave accelerator

In the past, the dielectric losses that results more power needed to establish the desired accelerating gradient, and the dielectric breakdown from high electric field intensities made the dielectric loaded accelerator not attractive. The recent development of high dielectric constant (ε~20-40), low loss materials (Q~10,000-40,000) brought a new look at this idea [5]. For implementing this type of dielectric loaded accelerator, there are still some potential problems [1, 2]:

- Dielectric breakdown
- Thermal heating
- Accumulation of surface charges on the dielectric
- Absorption of gases in the dielectric
- Dimensional tolerances.

At present, very little information of these problems is available, when the dielectric loaded waveguide is operated under ultra-high vacuum, within X-band frequency range, and with very high RF power. Whether these problems are fatal or not can only be answered through experiments. A prototype of dielectric loaded accelerating structure has been built for experimental investigation on those problems. The nominal operating frequency of that prototype is 11.424GHz.

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II. Construction and Bench Testing of X-band Dielectric Loaded Accelerating Structure Prototype

One faces a challenging problem when building an actual dielectric loaded traveling-wave accelerator because outer diameter of the dielectric ceramic tube (0.336") is much smaller that the width of the rectangular waveguide (0.9") which couples that external RF. The RF power is coupled through the slots on the wall of dielectric waveguide.

The challenging problem of coupling RF power from rectangular waveguide to the dielectric waveguide hindered the engineering progress of the proposed external powered dielectric accelerating structure for long time. We found that by using a combination of side-coupled irises and a tapered dielectric ceramic near the coupling iris one can efficiently couple the RF from the rectangular waveguide to the dielectric waveguide [6]. The total length of dielectric ceramics is chosen carefully to ensure the optimal transmission at the coupling slots. The schematic diagram of 11.4GHz dielectric loaded accelerator prototype is shown in figure 2. We have achieved >90% power coupling in the bench test. The parameters of prototype are shown in table I. Choice of the dielectric is Mg-Ti oxide that has dielectric constant of 20. And this material can be readily obtained from commercial vendors.

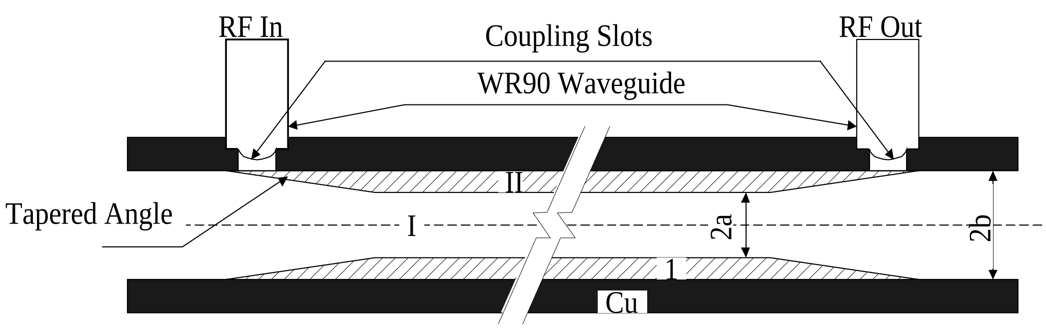

Figure 2. Scheme of a dielectric loaded travelling wave accelerator. Total length of the dielectric is 25 cm. The tapered angle is 8 degree. In the actual experiment, we use 1-inch long dielectric sections to fill the tube. Regions I: vacuum; II: dielectric

Table I. Dimensions and Physical Properties of the 11.4GHz Dielectric-lined Waveguide

Material	MgTi Oxide
Dielectric Constant ε	20
Tapered Angle	8°
Loss Tangent δ	10^{-4}
Inner Radius a	0.003m
Outer Radius b	0.00456m
HEM_{11} Mode Cut-off Frequency	9.96GHz
Group Velocity	0.057c
Attenuation	4dB/m
Power Needed for 10MV/m Gradient	2.6MW

The RF coupling scheme we used here is similar to the side-coupled method used for conventional disk-washer RF cavities. Impedance matching of the coupling slots is more difficult in the high dielectric constant case because the outer radius of the dielectric tube is much smaller than the width of waveguide. In order to achieve high efficient coupling, the dielectric tube near the coupling slot is tapered to serve as an impedance transformer. The tapered angle was chosen to be 8° for initial convenience. No other angles were tested, but it is not expected that the taper angle is critical, as long as the taper is gradual enough. A 25cm long prototype structure was constructed with the parameters in table I. The dielectric material was obtained from Trans Tech. The rectangular coupling slot dimension is 4.7mm(axial)x6.60mm(transverse). Figure 3 shows all parts of the X-band dielectric loaded accelerating structure prototype. Figure 4 shows the prototype after final assembly.

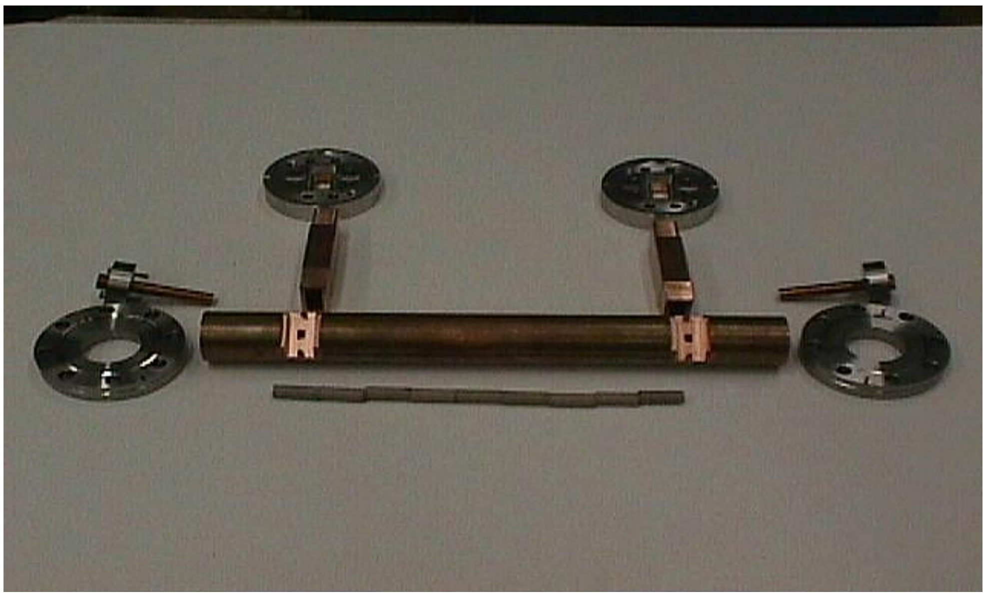

Figure 3. All Parts of the 11.4GHz dielectric loaded Prototype Structure

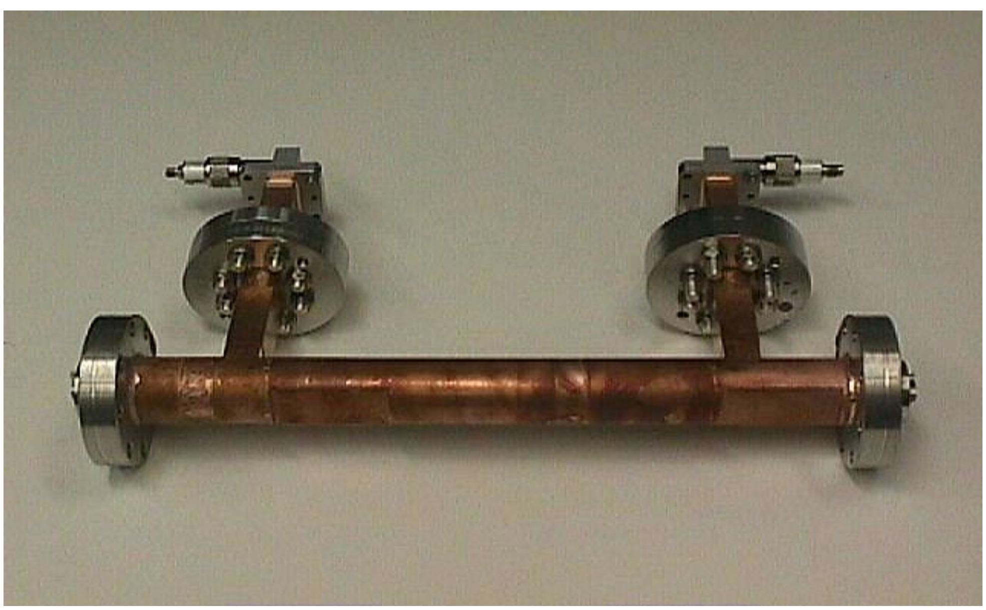

Figure 4.11.4GHz dielectric loaded Prototype Structure after Final Assembly

The schematic diagram of bench measurement setup is shown in figure 5. Figure 6 shows the actual setup.

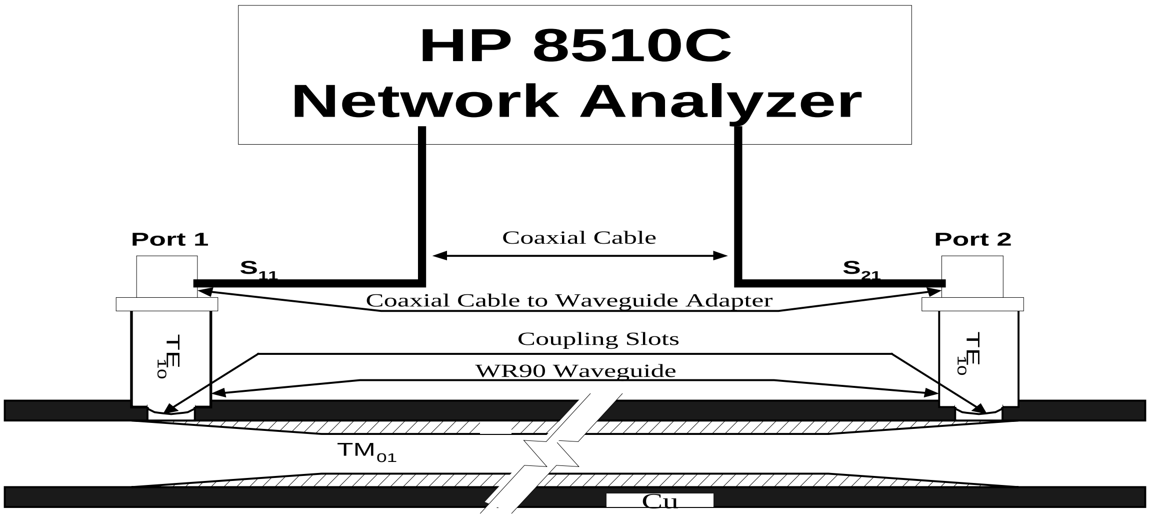

Figure 5.11.4GHz dielectric loaded Prototype Structure Bench Testing Diagram

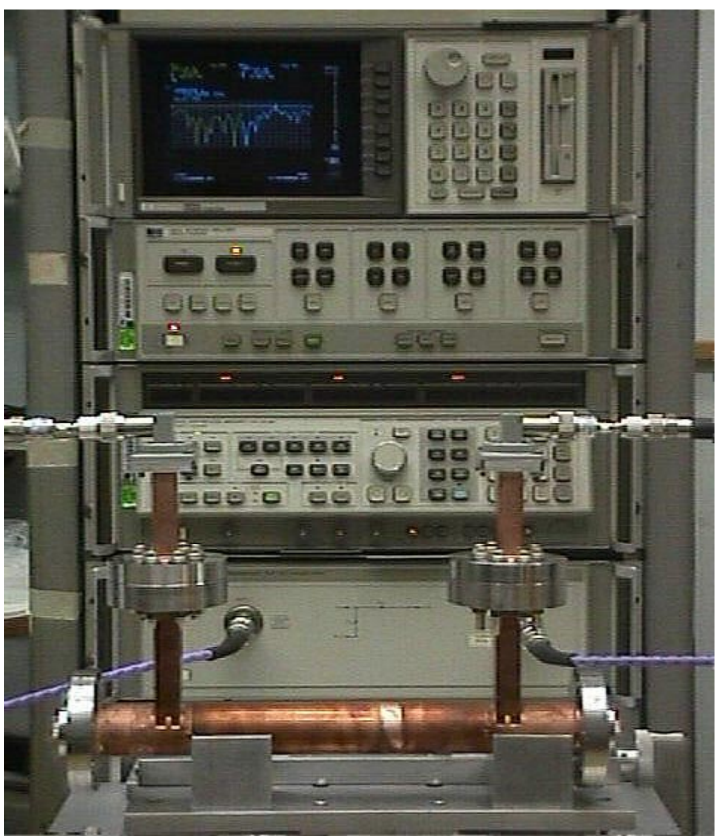

Figure 6.11.4GHz dielectric loaded Prototype Structure in Bench Testing

Figure 7 and 8 shows the bench measurement results of s_{11} and s_{21}, respectively. The maximum transmission between two ports is about –1.7dB at 11.421GHz. The minimum reflection at the input port is about –20dB at the same frequency.

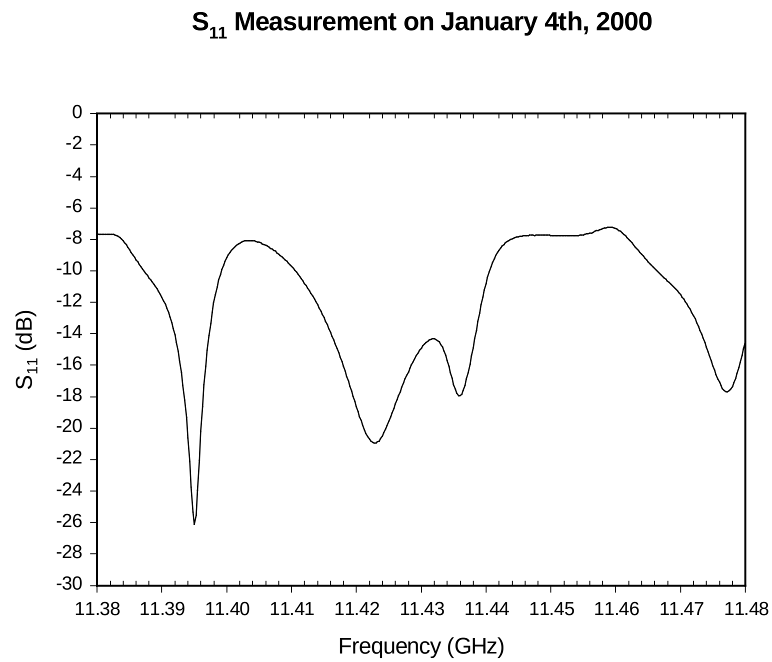

Figure 7. S_{11} measurement of 11.4GHz dielectric loaded accelerating structure prototype

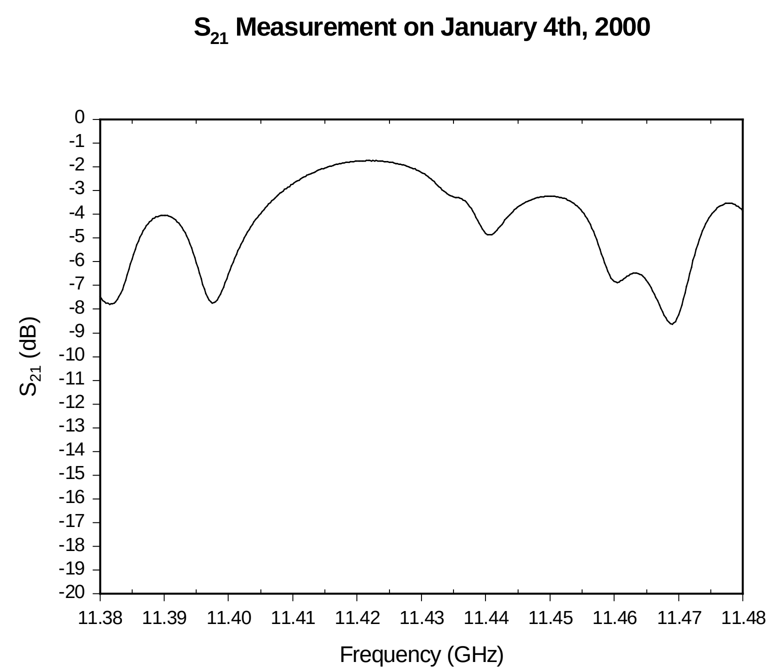

Figure 8. S_{21} measurement of 11.4GHz dielectric loaded accelerating structure prototype

Whether this dielectric loaded structure can satisfy the required vacuum level for high power testing has already been verified. Figure 9 shows the vacuum testing of this prototype structure with dielectric ceramics loaded. The pressure reading has reached 4.3×10^{-8} torr. Lower pressure level can be expected after longer pumping time.

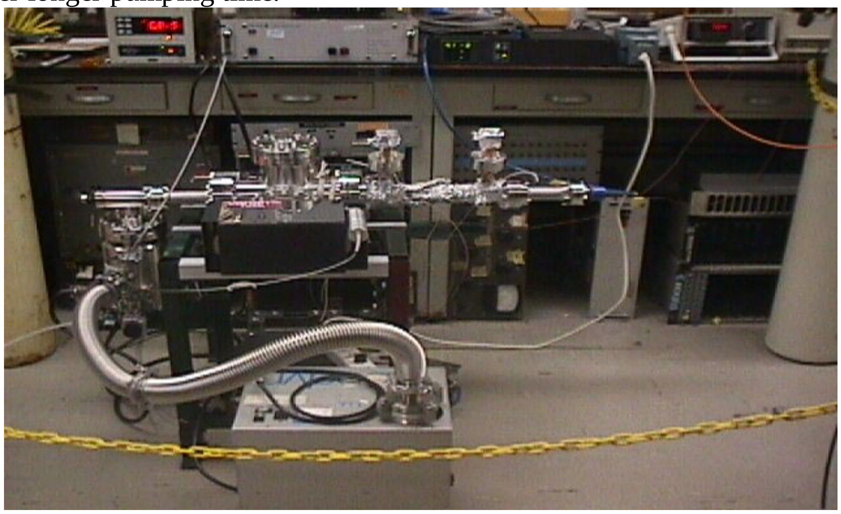

Figure 9. Vacuum testing of 11.4GHz dielectric loaded accelerating structure prototype

III. Conclusion

The prototype construction for an X-band dielectric loaded traveling-wave accelerating structure has been completed. The high power testing at SLAC will be conducted in the near future. The experimental investigations on this prototype will provide more knowledge for the development of dielectric based accelerator.

Reference:

1. G. Flesher and G. Cohn, Dielectric Loading for Waveguide Linear Accelerators, AIEE Transactions, 70, 887-893,1951
2. W. Gai, R. Konecny and J. Simpson, Externally Powered Dielectric Loaded Waveguides as Accelerating Structures, Proceedings of 1997 Particle Accelerator Conference, 636-638, Vancouver, May 1997
3. E. Chojnacki, etc. al., Journal of the Applied Physics, Vol. 69, 1991
4. W. Gai, C.-H. Ho, Modeling of the Transverse Mode Suppressor for Dielectric Wake-Field Accelerator, Journal of the Applied Physics, Vol. 70, 3955-3957, 1991
5. Trans-Tech., Catalog, 5520 Adamstown, Adamstown, MD 21710
6. P. Zou, W. Gai, R. Konecny, T. Wong, Construction and Testing of an 11.4 GHz Dielectric Structure Based Traveling Wave Accelerator, Proceedings of 1999 Particle Accelerator Conference, vol. 5, 3618-3620, New York, 1999